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Curve Flow-duration-Frequency. The flood modelling regime of the Wadi Mazafran catchment in the north of Algeria

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Abstract: Synthetic modelling of the flood regime is based on the overall knowledge of the hydrological regime in a catchment. The Flow-duration-Frequency (QdF) modelling is used to combine three parameters characterising flood with its mean or exceeded flow, its characteristic duration, and occurrence frequency. Which of these can be established locally at the extreme mean volume flow rates of a catchment reference hydrometric station? The determination of the reference QdF model in mean (volume) and exceeded flows requires two characteristics reflecting the flood regime in a catchment. The first is the characteristic flood duration and the second is the 10-year quantile of the annual maximum instantaneous flow. The comparison of the local situation to the reference QdF models enables to develop the final QdF model of the catchment and therefore the baseline QdF for exceeded and synthetic mono-frequency hydrographs. These are essential components in the study of flood risk mapping and the estimation of the instantaneous peak distribution from mean daily streamflow series.

Keywords: duration, flood, flood regime, flow, Flow-duration-Frequency (QdF) modelling, frequency, Mazafran

INTRODUCTION

Floods are among the natural disasters that cause loss of life and property damage, and are the most distributed risk on the planet. In some parts of the world, their dependence on climate change and the increasing demographic pressure on the banks of rivers make it increasingly worrying and difficult to manage. Algeria is one of the Mediterranean regions that are affected by floods that are usually caused by overflows of rivers. Several flood-related disasters were recorded in Algeria (Algiers in November 2001, Sidi Bel Abbes in April 2007, Ghardaïa and Bechar in October 2008, and recently Et-Taref in 2012, Tebessa and Constantine 2018, etc.) [YAHIAOUI *et al.* 2011]. Since the disaster of 10 November 2001 at Bab El-Oued in Algiers, with the toll of 750 victims, 115 people missing, and damage of USD 3.000.000, some measures have been introduced to study and possibly mitigate flooding [YAHIAOUI *et al.* 2014].

The risk of flooding is defined by the result of two independent components: hazard and vulnerability [GENDREAU, GILARD 1997; MOLIN VALDES 1994]. The hazard can be quantified as a function of water depth, event duration, and return period, whereas the vulnerability is the degree of damage caused by flooding. The direct and indirect economic damage is defined in the same dimension of the hazard as a function of water depth, event duration, and return period. When data are available for several years, the frequency analysis [YAHIAOUI 1997] and hydrometeorological methods as GRADEX and AGREGEE [MARGOUM 1992; GUILLOT, DUBAND 1967] are used to study flood regimes in order to predict rare and extreme quantiles of flood flows.

The objective of this article is to predetermine the Flow-duration-Frequency (QdF) model based on one of three reference models of Vandenesse, Florac or Soyans adapted for the catchment of Wadi Mazafran in the north of Algeria.

MATERIALS AND METHODS

STUDY AREA AND AVAILABLE DATA

The plain of Mitidja is located at the south of Algiers and extends geographically on the territory of Tipaza, Blida, Algiers and Boumerdes. It covers 1450 km^2 with an average length of 100 km and an average width of 14 km. The study area concerns the western part of the plain (western of Mitidja). It is limited in the north by the Mediterranean Sea, in the south by the bottom of the Atlas of Blida, in the east by the limits of the catchment area of Wadi Mazafran, and in the west by the limits of the catchment area of Wadi Djer and Wadi Bouroumi. The Wadi Mazafran catchment covers 1860 km², of which about 60% is in the mountains. The Wadi Mazafran occupies an area where three wadis, Bou Roumi, Djer and Chiffa meet. It is the part of the wadis with significant flood risk and they need to be monitored during precipitation as it has become stronger and more intense in recent years.

The catchment of Wadi Mazafran (Fig. 1) is characterised by a Mediterranean climate, alternation of a dry and hot season and a wet and cold season. The data required for the study include floods hydrographs recorded (Fig. 2) at the Fer a Cheval hydrometric station for 32 years, from 1981 to 2012.

Two important flood indices characteristic of the catchment must be determined for the Flow-duration-Frequency models. The first is the decennial annual instantaneous flow value *QIXA*10 and its corresponding duration *D*.

DETERMINING THE QUANTILE $QIXA_{10}$

Based on data recorded in 32 years, the series of instantaneous maxima flow *QIX* has been obtained by extracting independent flows over the threshold of 20 m^3·s^{-1} [Yahiaoui 2012]. The number of flows occurring in each year (Fig. 3). The frequency analysis consists of two parts, the first one estimates the distribution probability of the flows *QIX* occurring in the year, and the second one estimates the probability distribution of the number of events occurring in the same period. The probability distribution function in a given time is computed as follows:

$$F(x) \equiv P(X \leq x) = \sum_{k \geq 0} [H(x)]^k g(k) \tag{1}$$

where: $H(x)$ = cumulative distribution function of the flow events x, $g(k)$ = probability density function that k events occur in a given year.

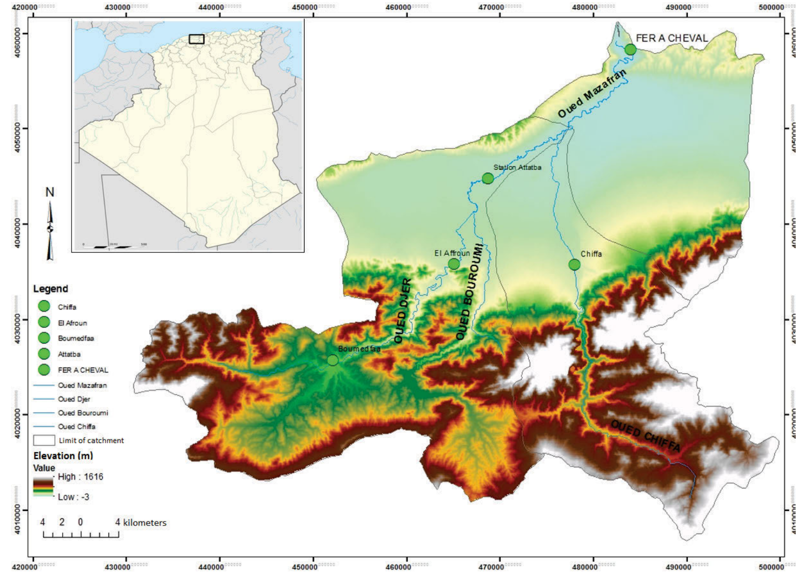


Fig. 1. Wadi Mazafran catchment; source: own elaboration

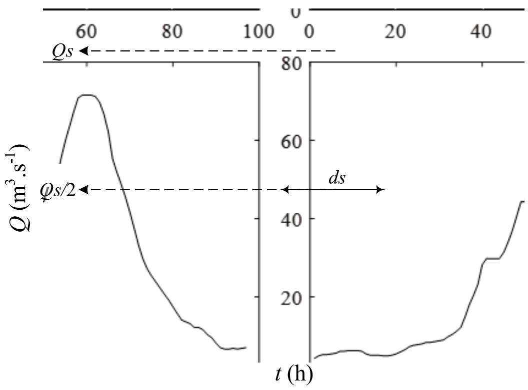


Fig. 2. Hydrograph of the flood of 27–30 Jan 1982; source: ANRH of Algiers

If $H(x)$, is assumed to be an exponential distribution with m and a the location and scale parameters, so:

$$H(x) = 1 - \exp\left(-\frac{x-m}{a}\right) \tag{2}$$

g(k), is assumed to be Poisson distributed, so:

$$g(k) = \frac{\lambda}{k!}\exp(-\lambda) \tag{3}$$

The Poisson parameter λ equals to the expected number of occurrences in each year is estimated by the mean of flow over threshold events, which equals to 4.3 (Fig. 3). From Equations (1), (2) and (3), $F(x)$ can be expressed by:

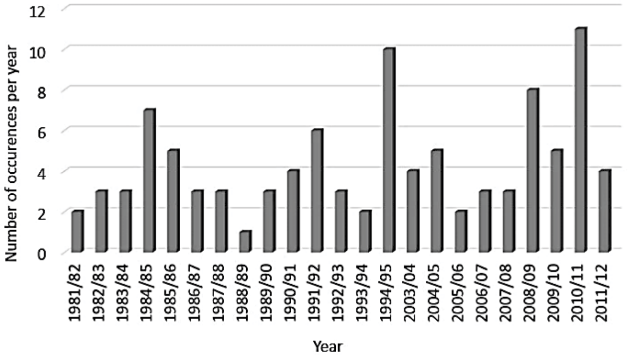


Fig. 3. Number of occurrences of instantaneous maxima flow over threshold per year; source: own study

$$F(x) = \exp\left[-\lambda \exp\left(-\frac{x-m}{a}\right)\right] \tag{4}$$

where: a and m can be estimated by the method of moments (Fig. 4) according to the mean and the standard deviation of the series of QIX over threshold ($\overline{QIX}$ = 106.73 $m^3 \cdot s^{-1}$ and S = 103.24 $m^3 \cdot s^{-1}$). So, $a = S$ = 103.24 $m^3 \cdot s^{-1}$ and $m = \overline{QIX} - a$ = 3.49 $m^3 \cdot s^{-1}$. Therefore, from Equation (4), the quantile $QIXA_T$ associated to the return period T can be obtained as:

$$\exp\left[-\lambda \exp\left(-\frac{QIXA_T - m}{a}\right)\right] = 1 - \frac{1}{T} \tag{5}$$

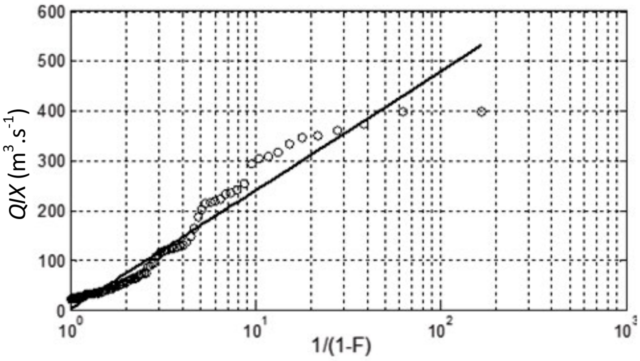


Fig. 4. Fitting and confidence limits of 95% of signification of the annual instantaneous maxima flow (QIX) in Wadi Mazafran; source: own study

Hence, for known values of λ, m and a, Equation (5) gives the values of quantiles of the annual instantaneous maxima flow in the Wadi Mazafran catchment as:

$$\begin{aligned} QIXAT &= m - a \ln\left[-\frac{1}{\lambda}\ln\left(1-\frac{1}{T}\right)\right] \\ &= \overline{QIX} + \left\{1 - \ln\left[-\frac{1}{\lambda}\ln\left(1-\frac{1}{T}\right)\right]\right\} S \end{aligned} \tag{6}$$

so,

$$QIXAT = 3.49 - 103.24 \ln\left[-\frac{1}{4.3}\ln\left(1-\frac{1}{T}\right)\right] \tag{7}$$

Equation (7), gives $QIXA_{10}$ = 386.41 $m^3 \cdot s^{-1}$, the characteristic flood of the Wadi Mazafran catchment.

DETERMINING THE DURATION *D*

For each recorded flood hydrograph (Fig. 2), two characteristics can be obtained, i.e. the peak flow rate Qs and its corresponding characteristic duration ds, the latter defined as the time that half of the peak Qs flow is continuously exceeded. In the plan (Qs, ds), the characteristic time of catchment flood D is defined as the value of the conditional median of the ds for the corresponding to the quantile $QIXA_{10}$ [CTGREF *et al.* 1980; 1982]. For the Wadi Mazafran catchment, the typical duration of the flood is estimated at four hours (Fig. 5). In the GRADEX method [MICHEL 1982], only one duration is used close to $2D$, further studies [JIN, GALÉA 1990] have shown some flexibility in choosing the duration in the interval [D/2, 5D] = [2, 20] hours.

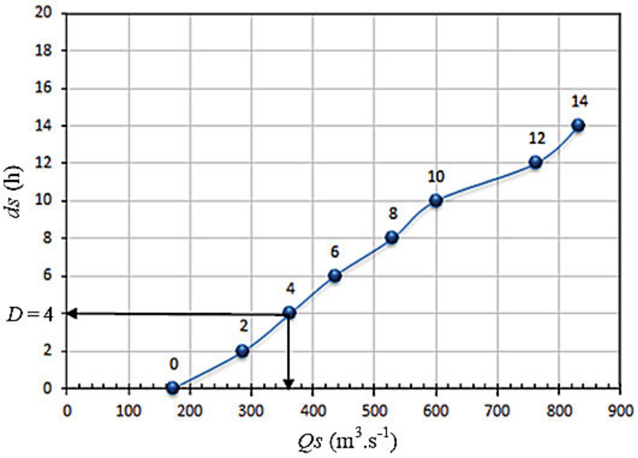


Fig. 5. Estimation of the characteristic duration D of the flood of Wadi Mazafran catchment; source: own study

LOCAL FLOW-DURATION-FREQUENCY

For a duration d ($t' \le t \le t' + d$) in recorded hydrograph $Q(t)$, two characteristics of flow can be defined: the mean flow (volume) VCd and the exceeded flow QCd:

$$VCd = \frac{1}{d}\int_{t'}^{t'+d} Q(t)dt \tag{8}$$

$$QCd = \min[Q(t)] \tag{9}$$

For the concerned year and duration d, all the independent values of VCd and QCd over a considered threshold (20 $m^3 \cdot s^{-1}$) are denoted by $VCXd$ and $QCXd$. For all the years, partial duration series in $VCXd$ or $QCXd$ and its occurrences can be analysed (Fig. 6) with the same method as in QIX series. So, the quantile $VCXd_T$ is expressed as in Equation (6) by:

$$VCXdT = \overline{VCXd} + \left\{1 - \ln\left[-\frac{1}{\lambda_d}\ln\left(1-\frac{1}{T}\right)\right]\right\} S_d \tag{10}$$

$\overline{VCXd}, S_d$ and λ_d = the mean of standard deviation (Fig. 7) and expected number of occurrences in each year of the $VCXd$ series. λ_d is estimated approximately at five occurrences per year for any

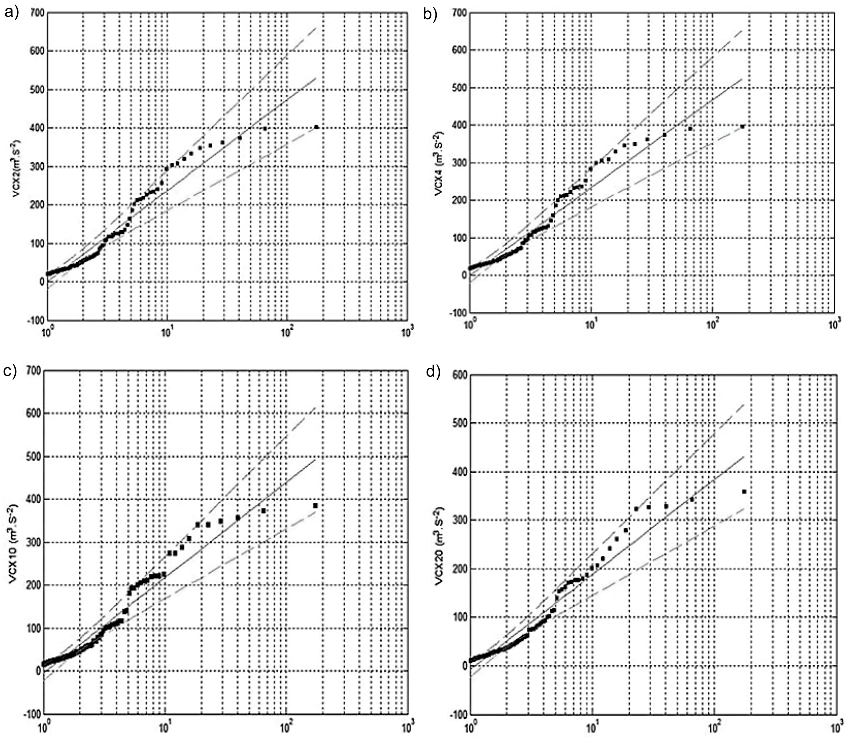


Fig. 6. Fitting and confidence limits at 5% significance of the exponential distribution to the maxima mean of samples (*VCXd*) with the duration: a) 2 h, b) 4 h, c) 10 h, d) 20 h; source: own study

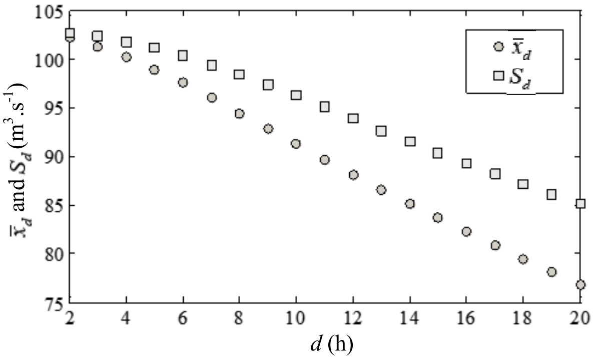


Fig. 7. Mean and standard deviation of the *VCXd* series; source: own study

duration. $VCXd_T$ is the local Flow-duration-Frequency approach (Tab. 1) which provides a continuous formulation of maximum mean (volume) flow quantiles as a function of both frequency and duration.

FLOW-DURATION-FREQUENCY REFERENCE MODELS APPROACH

The hydrometeorological models as in GRADEX and AGREGEE [Galéa, Prudhomme 1993; 1994] provide a connection from a certain return period [Margoum 1992; Michel 1982] in terms of mixing two distributions of probability. This is given by the formula below obtained from the GRADEX theory. The low frequency rates corresponding to $20 < T < 1000$ years [Margoum 1992]:

Table 1. Estimated quantiles of $VCXd_T$ (m³·s⁻¹) for Wadi Mazafran

Duration (h)	Values at return period *T* (years) equal to							
	2	5	10	20	50	100	500	1000
2	202.48	318.92	396.02	469.98	565.70	637.44	803.20	874.47
3	201.12	317.04	393.79	467.41	562.70	634.11	799.12	870.07
4	199.42	314.68	390.99	464.19	558.94	629.94	794.01	864.55
5	197.58	312.16	388.03	460.80	554.99	625.58	788.69	858.81
6	195.51	309.27	384.59	456.84	550.36	620.44	782.38	852.00
7	193.01	305.67	380.26	451.81	544.42	613.81	774.18	843.13
8	190.47	301.98	375.81	446.64	538.31	607.00	765.75	833.99
9	187.87	298.18	371.22	441.28	531.97	599.92	756.96	824.47
10	185.21	294.29	366.51	435.79	525.46	592.66	747.94	814.69
11	182.46	290.19	361.52	429.94	518.50	584.86	738.22	804.15
12	179.75	286.15	356.60	424.18	511.64	577.19	728.65	793.77

cont. Tab. 1

Duration (h)	Values at return period T (years) equal to							
	2	5	10	20	50	100	500	1000
13	177.03	282.06	351.60	418.31	504.65	569.35	718.86	783.14
14	174.45	278.19	346.88	412.77	498.05	561.96	709.64	773.13
15	171.86	274.29	342.11	407.16	491.37	554.46	700.28	762.96
16	169.34	270.49	337.47	401.71	484.87	547.18	691.18	753.09
17	166.89	266.81	332.98	396.44	478.59	540.14	682.39	743.55
18	164.50	263.23	328.60	391.31	472.47	533.29	673.84	734.26
19	162.19	259.78	324.38	386.36	466.57	526.69	665.60	725.32
20	159.94	256.37	320.22	381.47	460.75	520.15	657.43	716.45

Source: own study.

$$Q(T,\,d)=Q\left(T_g,\,d\right)+A_p(d)\ln\left(1+\frac{A_{pq}(d)}{A_p(d)}\frac{T-T_g}{T_g}\right)\tag{11}$$

where: $A_{pq}(d)$ is the GRADEX value of maximum for $T = T_g$ peak flow rate, T_g is the return period corresponding to the extrapolation (usually $T_g = 10$ years) and $Q(T_g, d)$ is the quantile of flow for the duration d in the return period T_g. It is expressed by:

$$Q\left(T_g,\,d\right)=B(d)+A_q(d)\ln T_g\tag{12}$$

where: $A_q(d)$ = GRADEX of flow floods, $B(d)$ = position parameter, and $A_p(d)$ the GRADEX of the rains.

In Equation (12), $Q(T, d)$, has an asymptotic tendency towards the GRADEX of maximum rainfall, which is all the less rapid as the $A_{qg}(d)/A_q(d)$ ratio is different from 1. This compares the incidence of the extrapolation threshold T_g on flood quantiles. The conditions of using this type of extrapolation are strict with respect to the duration of the project, and the conditions for the GRADEX maximum rainfall are different, depending on the *QCXd* or *VCXd*.

If the hypotheses formulated over the concept of hydrological regime are valid, and if this concept shows qualities of representativeness that are suspected, by identifying families of hydrological regime and discriminating characteristics of those families, it should be possible to translate this knowledge in terms of hydrological regime into a simpler mathematical form of use. The Flow-duration-Frequency method with the three associated reference models was developed for this purpose [Gilard 1998; Gilard *et al.* 1993].

The statistical modelling was carried out on several hundred hydrometric stations in Europe [Prudhomme 1995; Shuiteman *et al.* 1989; Sourisseau, Galéa 1996]. It indicated a typology of hydrological regimes that was summarized in three different catchment families. These can be represented by a specific incremental model. These models received continuous mathematical description for duration and return period variables to generalise their use.

The mathematical formulation of the Flow-duration-Frequency beams obtained on reference stations was considered in two parts in accordance with the formulae of the GRADEX method. This produced the Flow-duration-Frequency curves for reference basins. It has been shown that for an exponential distribution, which is adapted to extreme values, the parameters follow strictly decreasing functions of duration and can be expressed mathematically by the following homographic formulation [Grissolet *et al.* 1962]:

$$A_q(d),A_p(d),B(d)=\frac{1}{\alpha d+\beta}+\gamma\tag{13}$$

In the expressions of the GRADEX method, d is replaced by d/D and $Q(T, d)$ by $Q(T, d)/QIXA_{10}$ [Gilard 1998; Gilard *et al.* 1993]. The operational purpose of this mathematical formulation is to produce analytically the expression of $Q(T, d)$ in rare and observable domain:

for $0.5 \le T$ (year) ≤ 20

$$\frac{Q(T,\,d)}{QIXA_{10}}=\frac{A_q\left(\frac{d}{D}\right)\ln T+B\left(\frac{d}{D}\right)}{QIXA_{10}}\tag{14}$$

for $20 < T$ (year) ≤ 1000

$$\frac{Q(T,\,d)}{QIXA_{10}}=\frac{QCX\left(T_g,\,d\right)}{QIXA_{10}}+\frac{A_p\left(\frac{d}{D}\right)}{QIXA_{10}}\ln\left[1+\frac{A_q\left(\frac{d}{D}\right)}{A_p\left(\frac{d}{D}\right)}\frac{T-T_g}{T_g}\right]\tag{15}$$

where,

$$\frac{A_q\left(\frac{d}{D}\right)}{QIXA_{10}}=\frac{1}{x_1\frac{d}{D}+x_2}+x_3\tag{16}$$

$$\frac{B\left(\frac{d}{D}\right)}{QIXA_{10}}=\frac{1}{x_4\frac{d}{D}+x_5}+x_6\tag{17}$$

$$\frac{A_p\left(\frac{d}{D}\right)}{QIXA_{10}}=\frac{1}{x_7\frac{d}{D}+x_8}+x_9\tag{18}$$

where: $x_1, x_2, \ldots, x_9$ = parameters that have been defined for each model in mean (volume) flow *VCX* and exceeded flow *QCX* (Tabs. 2, 3).

So, the known values of $QIXA_{10}$ and D all the reference catchment Flow-duration-Frequency $Q(T, d)$ of Vandenesse, Florac and Soyans in both *VCX* or *QCX* can be calculated with the following formulas:

Table 2. Parameters x_i for the Flow-duration-Frequency models in mean flow *VCX*

Type of model	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Vandenesse	2.635	6.190	0.016	1.045	2.385	0.172	1.083	1.750	0.000
Florac	1.120	3.560	0.000	0.950	3.180	0.039	1.560	1.910	0.085
Soyans	0.870	4.600	0.000	1.070	2.500	0.099	0.569	0.690	0.046

Source: GILARD [1998].

Table 3. Parameters x_i for the Flow-duration-Frequency models in *QCX* exceeded flow

Type of model	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Vandenesse	3.970	6.480	0.010	1.910	1.910	0.097	3.674	1.774	0.013
Florac	3.050	3.530	0.000	2.130	2.960	0.010	2.780	1.770	0.040
Soyans	2.570	4.860	0.000	2.100	2.100	0.050	1.490	0.660	0.017

Source: GILARD [1998].

for 0.5 ≤ T (year) ≤ 20

$$\frac{Q(T,\, d)}{QIXA_{10}} = \left(\frac{1}{x_1\frac{d}{D} + x_2} + x_3\right)\ln T + \frac{1}{x_4\frac{d}{D} + x_5} + x_6 \tag{19}$$

for 20 < T (year) ≤ 1000

$$\frac{Q(T,\, d)}{QIXA_{10}} = \frac{Q(T_g,\, d)}{QIXA_{10}} + \left(\frac{1}{x_7\frac{d}{D} + x_8} + x_9\right)\ln\left(1 + \frac{\frac{1}{x_1\frac{d}{D}+x_2} + x_3}{\frac{1}{x_7\frac{d}{D}+x_9}}\frac{T - T_g}{T_g}\right) \tag{20}$$

The comparison of the local Flow-duration-Frequency of the catchment of Wadi Mazafran (Fig. 8) as is obtained by Equation (10) to the reference catchment Flow-duration-Frequency (Tabs. 4, 5, 6 and Fig. 9) allows to decide which type of a reference model can be applied to the flood regime of the catchment of Wadi Mazafran. The location of the catchment in the same family is not solely related to a simple dependence of rainfall patterns, but more generally to the type of flow patterns resulting from the rain flow complex. This does not allow for rainfall influence to be considered as the only criterion for selecting one of the three Flow-duration-Frequency (QdF) models to be applied to any catchment [GILARD 1998]:

- Vandenesse model, for catchments under oceanic influence,
- Florac model, for catchments under Mediterranean influence,
- Soyan model, for catchments under more continental influence.

These references Flow-duration-Frequency models of Vandenesse, Florac and Soyans are representative of catchments with a high surface flow. The differentiation of the standard Flow-duration-Frequency curves relative to each of them characterises a greater or lesser permeability of catchments. The Soyan model for catchments with a low rainfall storage capacity, and conversely, the Florac model when this storage and deferred refunds are substantial [GILARD 1998; GILARD *et al.* 1993]. Additionally, the size of the catchment influences its "storage capacity" [YAHIAOUI *et al.* 2011].

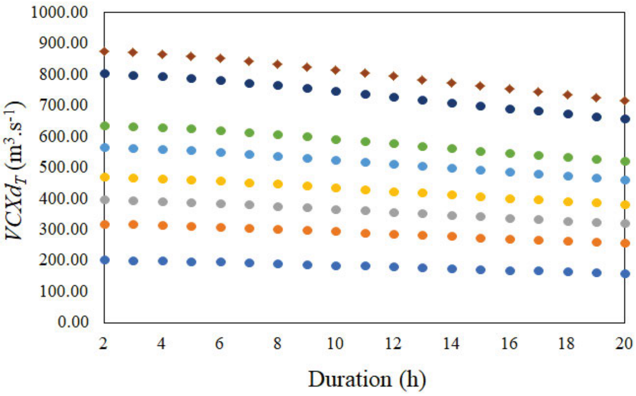


Fig. 8. Estimated *VCXdT* in Wadi Mazafran; source: own study

Table 4. Quantiles $VCXd_T$ (m^3·s^{-1}) calculated by the Flow-duration-Frequency model of Vandenesse

Duration (h)	Values at return period T (years) equal to							
	2	5	10	20	50	100	500	1000
2	239.20	292.00	331.94	371.88	477.20	568.80	816.75	930.42
3	225.37	274.37	311.43	348.50	444.59	527.49	750.28	852.09
4	213.64	259.41	294.02	328.64	417.04	492.78	695.07	787.27
5	203.57	246.54	279.05	311.56	393.45	463.20	648.48	732.72
6	194.82	235.37	266.05	296.73	373.04	437.69	608.61	686.17
7	187.15	225.58	254.64	283.71	355.19	415.45	574.11	645.96

cont Tab. 4

Duration (h)	Values at return period *T* (years) equal to							
	2	5	10	20	50	100	500	1000
8	180.37	216.92	244.56	272.20	339.46	395.90	543.94	610.88
9	174.34	209.21	235.58	261.95	325.47	378.58	517.35	580.00
10	168.94	202.30	227.53	252.77	312.97	363.11	493.72	552.60
11	164.08	196.08	220.28	244.49	301.72	349.22	472.58	528.12
12	159.67	190.44	213.71	236.99	291.55	336.68	453.56	506.12
13	155.66	185.31	207.74	230.16	282.30	325.30	436.35	486.24
14	152.00	180.62	202.27	223.92	273.86	314.92	420.71	468.18
15	148.64	176.32	197.26	218.20	266.12	305.42	406.43	451.71
16	145.54	172.36	192.64	212.92	259.00	296.69	393.33	436.62
17	142.68	168.70	188.38	208.05	252.43	288.64	381.28	422.74
18	140.04	165.31	184.42	203.54	246.34	281.19	370.16	409.94
19	137.58	162.16	180.75	199.34	240.69	274.28	359.86	398.09
20	135.29	159.22	177.33	195.44	235.43	267.85	350.29	387.08

Source: own study.

Table 5. Quantiles $VCXd_T$ ($m^3 \cdot s^{-1}$) calculated by the Flow-duration-Frequency model of Florac

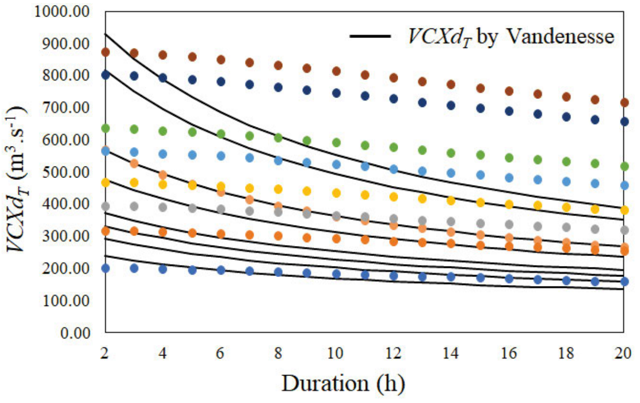
Duration (h)	Values at return period *T* (years) equal to							
	2	5	10	20	50	100	500	1000
2	185.70	271.60	336.57	401.55	537.61	646.13	918.21	1038.95
3	175.12	255.55	316.39	377.23	501.36	599.70	844.65	953.06
4	165.78	241.39	298.59	355.79	470.25	560.47	784.19	883.03
5	157.46	228.81	282.78	336.75	443.19	526.80	733.46	824.64
6	150.02	217.55	268.64	319.73	419.41	497.54	690.17	775.09
7	143.31	207.42	255.92	304.41	398.34	471.83	652.74	732.43
8	137.24	198.26	244.41	290.57	379.51	449.03	619.98	695.26
9	131.72	189.93	233.96	277.99	362.58	428.66	591.06	662.54
10	126.68	182.32	224.41	266.50	347.27	410.34	565.30	633.50
11	122.05	175.35	215.66	255.98	333.35	393.76	542.19	607.52
12	117.80	168.93	207.62	246.30	320.62	378.67	521.33	584.13
13	113.86	163.01	200.19	237.38	308.95	364.89	502.40	562.95
14	110.22	157.53	193.32	229.11	298.20	352.23	485.13	543.66
15	106.84	152.44	186.94	221.44	288.27	340.56	469.30	526.02
16	103.69	147.70	181.00	214.30	279.06	329.77	454.74	509.81
17	100.75	143.28	175.46	207.63	270.49	319.76	441.29	494.87
18	98.00	139.14	170.27	201.40	262.50	310.45	428.83	481.04
19	95.41	135.27	165.41	195.56	255.03	301.76	417.25	468.21
20	92.99	131.62	160.85	190.07	248.03	293.63	406.45	456.26

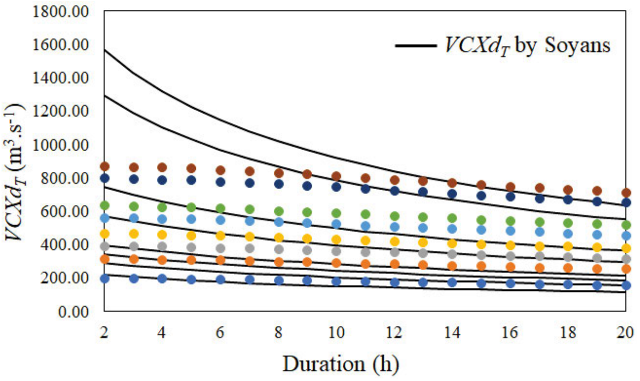
Source: own study.

Table 6. Quantiles $VCXd_T$ ($m^3 \cdot s^{-1}$) calculated by the Flow-duration-Frequency model of Soyans

Duration (h)	Values at return period T (years) equal to							
	2	5	10	20	50	100	500	1000
2	218.65	288.94	342.11	395.27	571.69	748.33	1298.73	1568.67
3	206.15	273.52	324.49	375.45	540.00	701.45	1193.34	1431.82
4	195.36	260.05	308.99	357.93	512.17	660.95	1106.10	1319.97
5	185.94	248.16	295.23	342.30	487.50	625.56	1032.49	1226.57
6	177.65	237.58	282.92	328.25	465.46	594.33	969.43	1147.25
7	170.29	228.09	271.81	315.53	445.64	566.53	914.71	1078.93
8	163.69	219.51	261.73	303.96	427.69	541.60	866.71	1019.40
9	157.76	211.72	252.55	293.37	411.36	519.11	824.23	967.00
10	152.38	204.61	244.12	283.64	396.43	498.69	786.32	920.49
11	147.48	198.09	236.37	274.66	382.72	480.07	752.27	878.89
12	143.00	192.08	229.21	266.34	370.08	463.01	721.49	841.45
13	138.89	186.53	222.57	258.62	358.38	447.32	693.53	807.54
14	135.09	181.38	216.40	251.42	347.53	432.83	667.99	776.68
15	131.59	176.59	210.64	244.69	337.43	419.40	644.57	748.47
16	128.33	172.13	205.26	238.39	328.00	406.92	623.00	722.56
17	125.30	167.95	200.21	232.47	319.17	395.29	603.07	698.69
18	122.47	164.03	195.47	226.91	310.90	384.43	584.60	676.61
19	119.82	160.35	191.01	221.66	303.13	374.25	567.42	656.12
20	117.34	156.88	186.79	216.71	295.80	364.69	551.41	637.05

Source: own study.





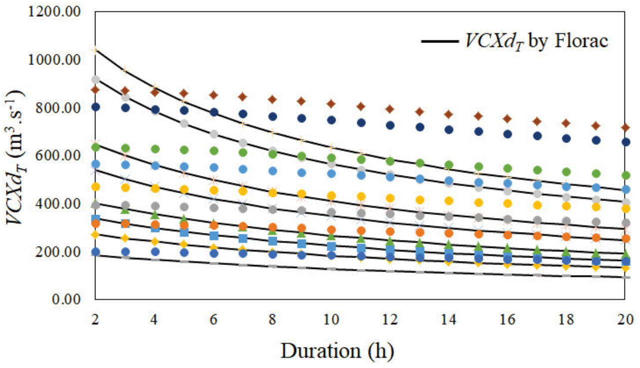


Fig. 9. Comparison between an estimated and calculated quantiles of $VCXd_T$; source: own study

RESULTS AND DISCUSSION

In case the GRADEX of rainfall is not available for different durations, the performance of one of the reference models is evaluated using calibration and validation. Thus, three accuracy criteria were used for a particular return period: Nash criteria [NASH, SUTCLIFFE 1970], linear tangent (TL) [YAHIAOUI *et al.* 2011], and the root mean square error ($RMSE$) [HYNDMAN, KOEHLER 2006]. Those criterions are positioned between the $VCXd_T$

estimated by Equation (10) and the $VCXd_T^{\text{model}}$ calculated by one of the Flow-duration-Frequency reference models (Vandenesse, Florac and Soyans) as:

$$\mathrm{Nash}(T) = 1 - \frac{\sum\limits_{d=2}^{20} \left(VCXd_T - VCXd_T^{\text{model}}\right)^2}{\sum\limits_{d=2}^{20} \left(VCXd_T - \overline{VCXd_T}\right)^2} \tag{21}$$

where: $\overline{VCX_T}$ = the mean of the flows $VCX2_T$, $VCX3_T$, ... , $VXC20_T$.

$$\mathrm{TL}(T) = 1 - \frac{\sum\limits_{d=2}^{20} VCXd_T . VCXd_T^{\text{model}}}{\sum\limits_{d=2}^{20} \left(VCXd_T\right)^2} \tag{22}$$

$$\mathrm{RMSE}(T) = \left[\frac{1}{19}\sum_{d=2}^{20} \left(VCXd_T - VCXd_T^{\text{model}}\right)^2\right]^{1/2} \tag{23}$$

According to the results obtained for relevant return periods of 2, 5, 10, 20, 50, 100, 500, and 1000 years (Figs. 10, 11 and 12), and to the climatic conditions of the catchment of Wadi Mazafran, the Flow-duration-Frequency reference model adapted in *VCX* is rather the Florac model than the Vandenesse and Soyans models.

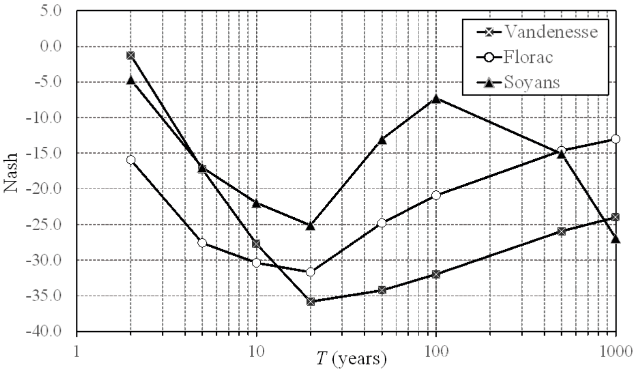


Fig. 10. Coefficient of Nash for the three standard models (Soyans, Florac and Vandenesse) in Wadi Mazafran; *T* = return period; source: own study

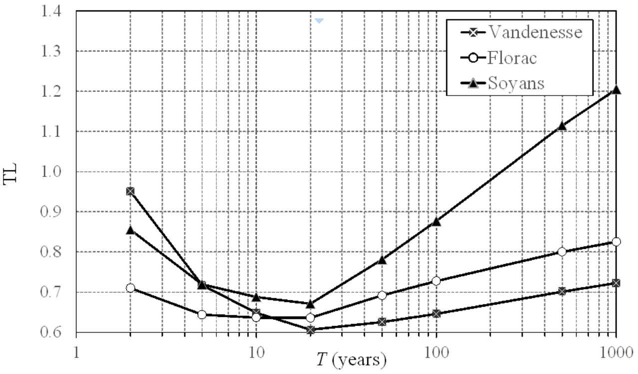


Fig. 11. Criterion of the tangent of the linear straight (*TL*) for the three standard models (Soyans, Florac and Vandenesse) in Wadi Mazafran; source: own study

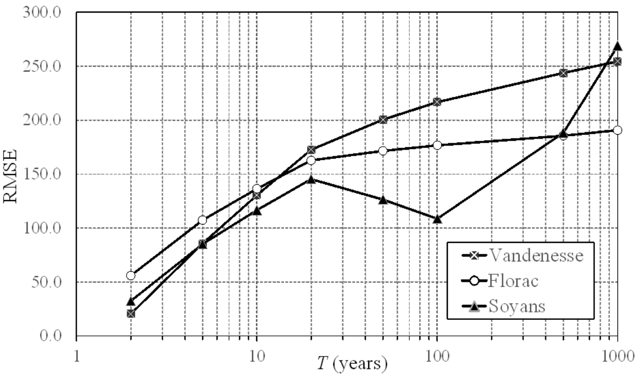


Fig. 12. Root mean square error (*RMSE*) coefficient for the three standard models (Soyans, Florac and Vandenesse) in Wadi Mazafran; source: own study

Thus, the Flow-duration-Frequency reference model in *QCX* is of the Florac too and it can be expressed as (Fig. 13):

for 0.5 ≤ *T* (year) ≤ 20,

$$QCXd_T = 386.41\left(\frac{1}{3.05\frac{d}{4}+3.53}\ln T + \frac{1}{2.13\frac{d}{4}+2.96} + 0.01\right) \tag{24}$$

for 20 < *T* (year) ≤ 1000,

$$QCXd_T = QCXd_{10} + 386.41\left(\frac{1}{2.78\frac{d}{4}+1.77} + 0.04\right) \ln\left(1 + \frac{\frac{1}{3.05\frac{d}{4}+3.53}}{\frac{1}{2.78\frac{d}{4}+1.77}}\frac{T-10}{10}\right) \tag{25}$$

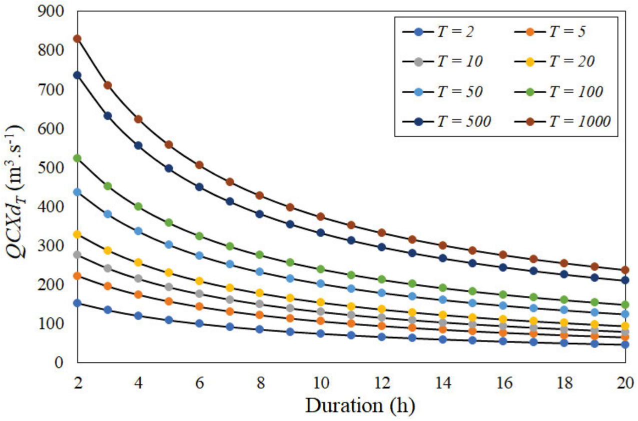


Fig. 13. Flow-duration-Frequency of *QCX* of Wadi Mazafran catchments; *T* = return period; source: own study

CONCLUSIONS

The model of Flow-duration-Frequency is very important in the study of the flooding in terms of hazard and vulnerability. For the hazard, based on the mono-frequency hydrograph with a hydrodynamic calculus, the flooded area can be determined. For the vulnerability, the Flow-duration-Frequency in the exceeded flow *QCX* can be used.

The advantage is the determining a Flow-duration-Frequency reference model based only on hydrometric data as the two characteristics $QIXA_{10}$ = 386.41 $m^3 \cdot s^{-1}$ and D = 4 h. In the case of Wadi Mazafran, the comparison of maximum mean quantile (volume) flow *VCX* with the other quantiles of Vandenesse, Soyans and Florac in multi-duration and in multi-frequency led to the adoption of the Flow-duration-Frequency of Florac as an adapted model which can be used to study floods.

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